Another line of enquiry started by Rutherford when he succeeded in transmuting Nitrogen into Oxygen with emission of hydrogen by bombarding Nitrogen with α-particles has been followed up in recent years with great success. Almost every element has now been converted into some other and new radioactive elements have been artificially produced by Curie and Joliot and Fermi and others. The missiles at the disposal of the physicist have also multiplied; α-particles, protons, diplons (heavy hydrogen nuclei) and neutrons have all been employed for this purpose. Cockcroft and Walton and Lawrence and others have refined experimental technique to such an extent that protons and deutons can now be given energies almost equivalent to that of the α-particles provided by Nature and the corresponding progress in the programme of transmutation has been extensive. Thus when Li_6 is bombarded by a deuton or Li_7 by a proton we get two α-particles which have about ten times the energy of the bombarding particles. The internal energy of the nucleus has thus been set free to some extent. Who shall limit the possibilities inherent in this achievement? Gladstone lived to levy a tax on an industry developed from Faraday's discovery. Hertz's discovery has revolutionised modern methods of communication. What practical possibility lying latent in the nucleus may not become an accomplished fact and what revolutions may it not bring about?

North Bihar Earthquake of January 15, 1934.*

By S. K. Banerji,
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THE earthquake which occurred in North Bihar on January 15, 1934, had many important peculiarities. The shock was felt over an area of not less than 3 million square miles—an area which is perhaps greater than that of any earthquake recorded during the last 100 years. An important feature which has been prominently brought to notice is the inequality of propagation of surface vibrations in different directions. These were felt at greater distances towards the south and the west than the north and the east, the Himalayas in the north and the Assam and Burma mountains in the east acting as barriers and damping them out considerably. That these mountain folds and the fault planes which bound them should obstruct the normal propagation of surface waves is what we should expect from the theory of elasticity.

An earthquake of severe intensity has usually an energy of the order of 10^{21} ergs but the present earthquake appears to have energy slightly greater than 10^{22} ergs. There are several methods by which the calculation of the energy of the earthquake can be made, but the simplest one is to use the results obtained theoretically by Nakano that for an earthquake of shallow focus 0·4 of the energy sent out from a compressional disturbance and 0·9 of that from a distortional one goes into surface waves. If then we estimate by means of seismograms the velocity of ground movements at some fixed distance, say 200 km., all round and also estimate the length of the wave train carrying most of the energy, we can immediately calculate the total energy of the earthquake. To illustrate the method of calculation, we would estimate that the mean velocity at a distance of 200 km. was 250 cm/sec. Since the mean density of surface rocks is about 2·7, the kinetic energy per unit volume is 9×10^4 ergs. On the average the potential energy is the same as the kinetic energy, and, therefore, the total energy per unit volume is $1{\cdot}8 \times 10^5$ ergs. Now the length of the part of the wave train carrying most of the energy

= mean velocity of surface waves × time taken to pass over a given place

$= 4 \times 10^5 \times 10 \times 60 = 2{\cdot}4 \times 10^8$ approximately.

Integrating over a circle of radius 200 km., we see that the energy of surface vibrations

$= 1{\cdot}8 \times 10^5 \times 2{\cdot}4 \times 10^8 \times 1{\cdot}2 \times 10^8 = 5 \times 10^{21}$ ergs.

According to the results obtained by Nakano, this is only a fraction of the total energy. Taking dissipation and other factors into account it would seem that the total energy is slightly greater than 10^{22} ergs. It is easily seen that this estimate of the total energy is not much affected, if we estimate a slightly greater or smaller value for the velocity

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* Based on the opening speech at the symposium held at the Indian Science Congress, 1935.

or the duration of the length of wave train or both at a distance of 200 km.

An energy of the order of 10^{22} ergs could be produced by the fracture of a quadrangular rock of dimensions 150 km. × 100 km. and thickness 10 km. If *a* be the length, *b* the breadth, and *2h* the thickness of a quadrangular rock, then its potential energy when bent by couples is

$$\frac{1}{3}\,\frac{Eh^3}{1-\sigma^2}\left[\left(\frac{1}{R_1}+\frac{1}{R_2}\right)^2-2\,(1-\sigma)\,\frac{1}{R_1R_2}\right]ab$$

where R_1, R_2 are the radii of curvature, E the Young's modulus and σ the Poisson's ratio. When the rock cracks, this energy is released. It is important to notice that this expression involves thickness in the third power but the length and breadth only in the first power. It is, therefore, the thickness which contributes most to the amount of energy released. We have no observational evidence in regard to the amount of bend which a plate of rock of large dimensions can stand before rupture, but, according to definition, if O is the centre of the rock, and if a plane through the normal and a principal axis of the indicatrix cut the extremities of the rock in the diameter QVQ′, then the radius of curvature R is given by $2R \cdot OV = QV^2$. But QV is either 75 km. or 50 km. according as the plane passes through the major or the minor axis of the indicatrix. It would be safe to assume that the rock will crack if OV become as large as 100 metres† (Fig. 1). This would make R_1 and R_2 to be of the

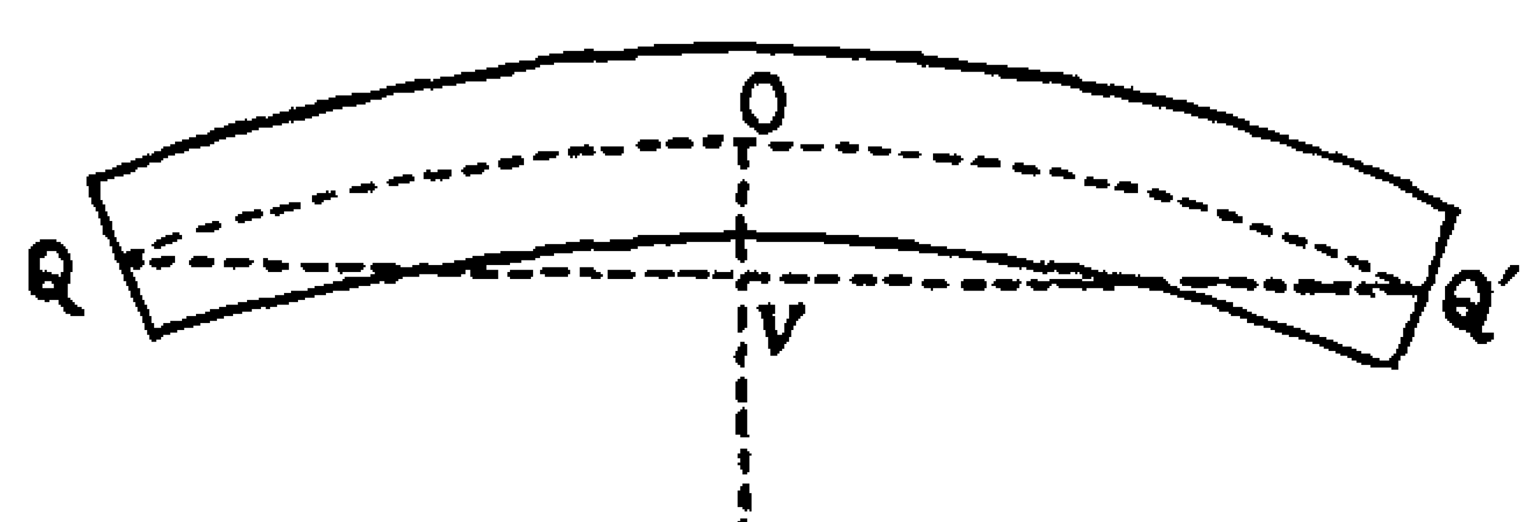

Fig. 1.

order 10^{10} cm. and 10^9 cm. respectively. With these values for R_1 and R_2 it is easily seen from the formula that the amount of energy which would be released by a bent quadrangular rock of dimensions 150 km. × 100 km. × 10 km. is of the order of 10^{22} ergs. If the thickness was less than 10 km., its length and breadth would have to be considerably greater than 150 km. and 100 km. respectively in order to give the energy of this magnitude. This would suggest that the focus of this earthquake must have covered a wide volume and the epicentral tract a fairly wide area. This is confirmed by the observations[1] made by the Geological Survey.

The very great preponderance of surface waves in this earthquake, as well as the type of movements in the preliminary and the secondary phases all suggest that this earthquake had a shallow focus.[2] If we estimate the depth ot focus from the relative importance of the different phases in the seismogram, we find that its upper surface was probably not lower than 15 km. From an analysis of the 'delay in starting' of the phases $\bar{P}$, P*, P, $\bar{S}$, S*, S, Ray[3] has recently estimated the depth of focus to be about 13 km. With this information in our possession, the question arises whether the theory of elasticity can make any definite contribution to the search for the cause of this earthquake.

It is almost certain that isostatic compensation holds in the case of such large mountains as the Himalayas. For, suppose that compensation did not hold, and that the Himalayas could be supported by the strength of the crust and the substratum. Calculation by the method given by Love[4] shows that the stress differences required to support mountains of height 10,000 metres above the adjacent valleys in a uniform crust would be about 10^9 dynes/cm.^{2} This is near the crushing strength of basalt, which could, therefore, just support the Himalayas if the stresses necessary could be distributed over an infinite depth. The Himalayas apart from being very high are of such large horizontal extent that they would produce breaking stresses in the lithosphere assumed to be of finite thickness. It is therefore very likely that they are bounded by fault planes so that they can move up and down independently, that is to say, float on the lithosphere and undergo up and down movements without disturbing the

† Surface earthquake waves which usually have wave-lengths of 60 or 70 km. invariably cause extensive cracks if they have amplitudes as large as one metre. The estimate of 100 metres for OV would thus appear to be an overestimate and not an underestimate. *A smaller value for OV would require greater thickness for the rock to yield the same energy.*

1 *Rec. of the Geological Survey*, **1931**, **38**, 177.

2 *Phil. Mag*, 1925, **49**, 65.

3 *Curr. Sci.*, 1935, **3**, 298.

4 *Some Problems of Geodynamics*, pp. 38–48; *Jeffrey's Earth*, pp. 178-202.

surface crust over the continents. But can relationship between the mountains and the continent be so simple as this? The fault planes being planes of fractures are probably inclined to the vertical. A clear gap does not apparently exist. There are probably huge rocks connecting the mountains and the continents across the fault planes. Any upward or downward movement of the mountains will necessarily introduce considerable stress in these rocks and if the elastic limit is reached, breaking will occur. Was a process like this the cause of the present earthquake? The upward motion of the mountains can of course occur as a consequence of denudation and if they are floating more or less independently of the continents the gravity anomalies found in the Gangetic plain and elsewhere are probably not of much importance as undoubtedly the strength of the continental crust, *i.e.*, the cohesion of the materials forming the continental crust, is able to support a small departure from perfect isostacy.

A theory of the above kind can only stand if it can be supported by geological observations. Such observations[5] have shown that the main epicentral tract has the form of an elongated ellipse and that it is situated at a distance of about 35 km. from the boundary fault (Fig. 2). If P be the greatest principal stress at any point in a rock and R be the least, the fault planes will, according to the theory developed by Mohr, Navier and others, be inclined at angle θ to the direction of P, given by $(P - R)(\sin 2\theta + \mu \cos 2\theta) - \mu(P + R) =$ a maximum. This equation means that along the planes of fracture the tangential stress diminished by the resistance to movement which is due to internal friction must be maximum, and gives $\theta = 22\frac{1}{2}°$ for $\mu = 1$. This result[6] is supported by observations, for, in the case of normal faulting it is known that P is very nearly vertical and R horizontal, and that normal faults are inclined to the vertical at an angle slightly greater than $22\frac{1}{2}°$. The faults cannot, however, be along a straight line, such as OA (or OA′

[5] *Rec. of Geological Survey*, *ibid.*

[6] *Beiträge Zur. Geophysik*, 1934, **43**, 5.

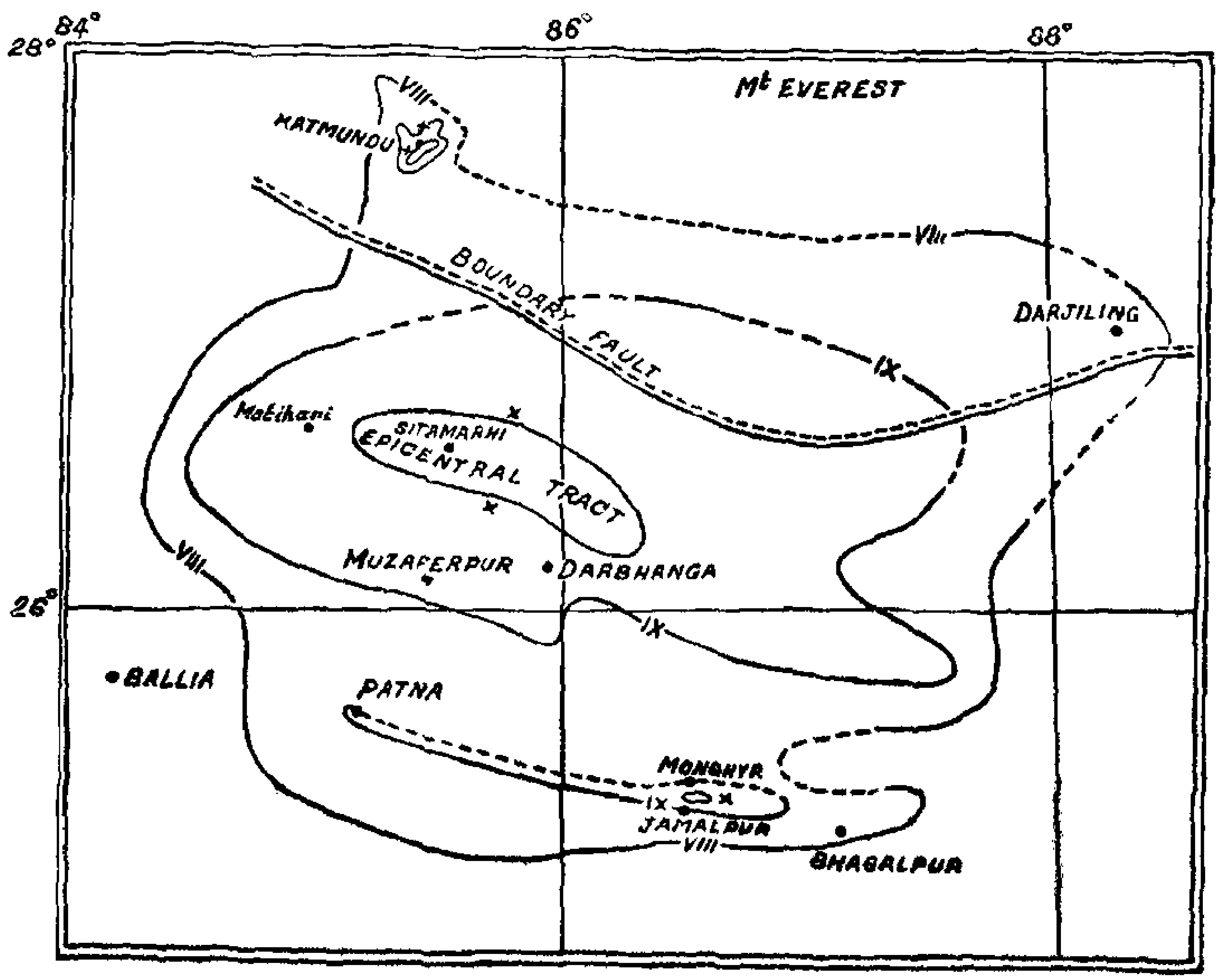

Fig. 2.

Epicentral Tract, isoseismal lines and boundary fault

(Based on the *Report of Geological Survey of India*).

if θ has a greater value than $22\frac{1}{2}°$) (Fig. 3).

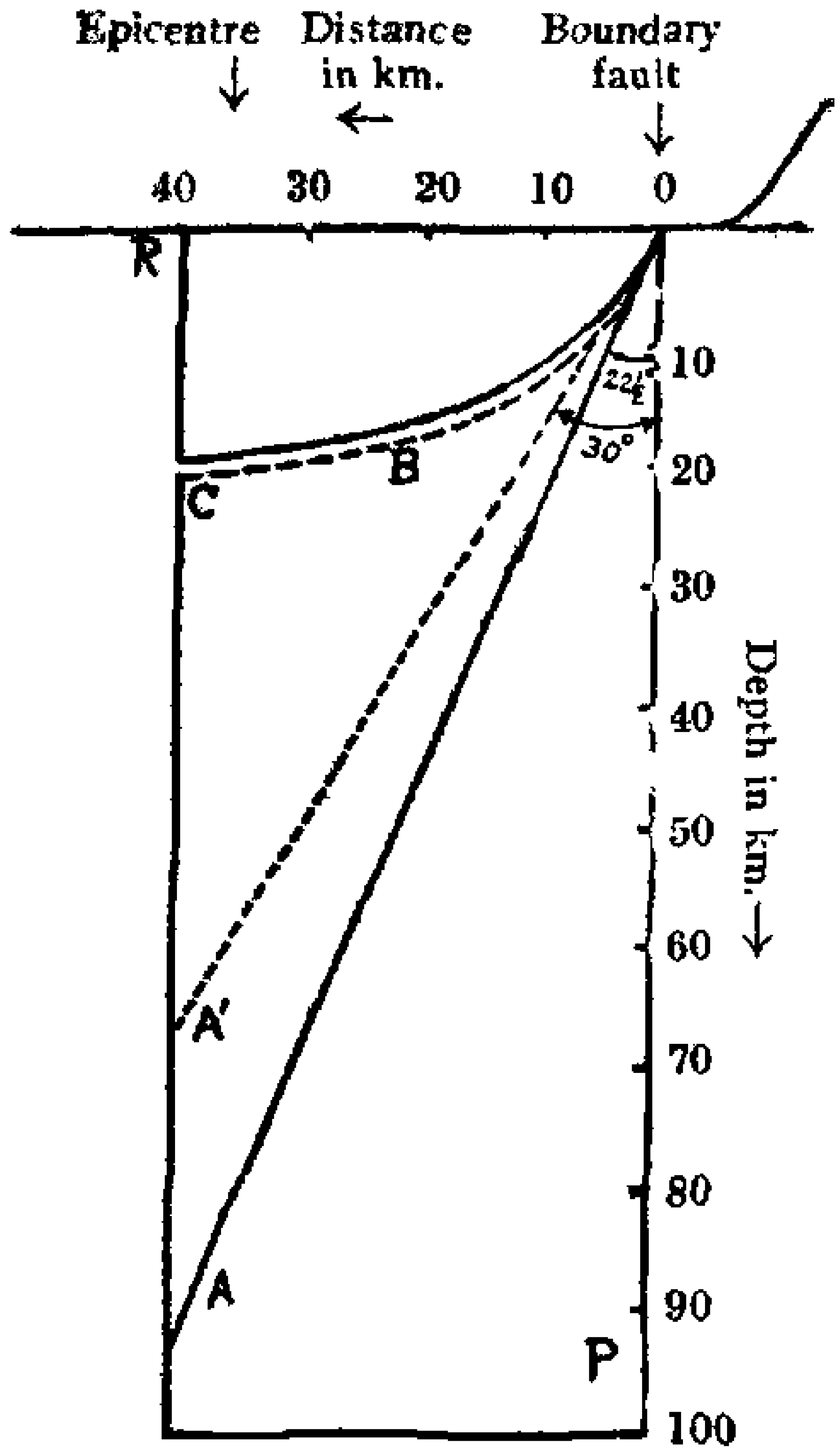

Fig. 3.

Vertical Section through epicentre and nearest point of boundary fault.

For, observations as well as theory of fractures[7] produced by loading always indicate that they lie along a curve such as OBC. The depth of the faults below the observed epicentral tract will therefore be about 20 km., and if an elongated rock of dimensions 150 km. × 100 km. and thickness 10 km. (rectangular, elliptical or other shape) was lying across the fault at this depth and was strained, it could by fracture give the energy required for the production of the earthquake. The two subsidiary epicentral tracts near Khatmando and Monghyr were probably induced by a major crack of this kind.

The earthquake occurred on a new moon day, and on such a day we get a body tide due to the elastic yielding of the solid material of the earth, such that the height of the oceans, as measured by the rise and fall of the sea, relative to the land is reduced to about $\frac{2}{3}$ of the true equilibrium height (if the rigidity of earth be assumed to be the same as that of steel). On that day also an atmospheric disturbance was passing over *Northern India* and *Darwin* has shown that if the difference of barometric pressure between consecutive regions of "high" and "low" pressures be 5 cm. of mercury and if the centres of "high" and "low" be *1,500 miles apart, then as a consequence of* the yielding of the ground, it will be 9 cm. higher under the barometric depression than under the elevation. These causes could, therefore, conceivably have served to produce a kind of trigger action.

[7] Banerji, *Bulletin Cal. Math. Soc.*, 1921, **12**, 93.

Some Recent Advances in Indian Geology.*

By W. D. West,
Geological Survey of India.

5. The Geology of Salt Range.

THIS comparatively small range of mountains in the northern Punjab has long been regarded as the show locality of Indian geology. Its fairly complete geological record, its abundant fossils and its complicated structure have combined to make it a place of great attraction to geologists. Bound up with the correct interpretation of its structure is the question of the age of the Saline series, concerning which almost every geologist who has visited the Salt Range seems to have propounded a theory. The problem, it will be recollected, lies in the fact that while in the Salt Range the Saline series underlies rocks of Cambrian (or possibly pre-Cambrian) age, in the Kohat district, only 17 miles away, it underlies rocks of Upper Nummulitic (Middle Eocene) age. And since in the latter place it was considered by D. N. Wadia and L. M. Davies to be of lower Eocene age,[1] a view subsequently corroborated by E. R. Gee,[2] its stratigraphical position in the Salt Range was difficult to understand.

There is no need to summarise the early stages of this controversy. Suffice it to say that Sir Edwin Pascoe, as a result of his

* Published with the permission of the Director, Geological Survey of India.

[1] *Trans. Min. Geol. Inst. Ind.*, 1929, **24**, 202.

[2] *Rec. Geol. Surv. Ind.*, 1931, **65**, 20; and *Curr. Sci.*, 1934, **2**, 461.